International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 9, Issue 5, Oct 2019, 1151–1170

DESIGN & ANALYSIS OF CYLINDRICAL DUCT AND SPIRAL RESONATORS FOR ATTENUATION OF PASSIVE NOISE CONTROL

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ABSTRACT

In this paper, design of gradual expansion cylindrical duct, design of Spiral Resonator were modelled by Pro-ENGINEER 5.0 Wildfire. Four Models of cylindrical duct were prepared such as Model-I, II, III & IV. Model-I is a simple circular duct, Model-II is a spiral resonator in cylindrical duct, Model-III is a single spiral resonator in gradual expansion cylindrical duct of different offset starting from '0' mm,'50' mm,'100' mm,'150' mm,'200' mm,'250' mm and '300' mm, and Model-IV is a double spiral resonator in cylindrical duct of different offset starting from '0' mm,'50' mm,'100' mm,'150' mm,'200' mm, and '250' mm. Then comparison were made with Model-I with other three models and analyzed by using ANSYS fluent 14.5 Software. Transmission Loss was calculated by the difference between the outgoing power at the outlet 'w_o' and the incoming power at the inlet 'w_i'. Finally it was concluded that the acoustic attenuation performance of Model- III is increases with increase the distance between Spiral Resonator and the inlet of the Gradual Expansion Chamber. In Model - IV, there is visible strong minimization of sound attenuation of two Spiral resonators when placing them one by one. Presented results shows that Spiral Resonator can be an effective additional sound attenuation element for ducted systems.

KEYWORD: Passive Noise Control, Cylindrical Duct, Gradual Expansion Cylindrical Duct, Single & Double Spiral Resonators

Original Article

Received: May 07, 2019; **Accepted**: May 27, 2019; **Published**: Oct 04, 2019; **Paper Id**.: IJMPERDOCT2019102

1. INTRODUCTION TO SOURCES OF PASSIVE NOISE

Sound is essential to our daily lives, but noise is not. Noise is generally used as an unwanted sound, or sound which produces unpleasant effects and discomfort on the ears. Vibrating objects produces sound. Regardless of what vibrating object is creating the sound wave, the particle of the medium through which the sound moves is vibrating in a back and forth motion at a given frequency. The frequency of a wave is measured as the number of complete back-and-forth vibrations of a particle of the medium per unit of time. A commonly used unit for frequency *(f)* is the Hertz (abbreviated Hz). The wavelength *(λ)* of a wave is the distance, which a disturbance travels along the medium in one complete wave cycle. The speed of a sound wave is mathematically related to the frequency and the Wavelength of the wave and is given, $v = \lambda \times f$. Noise can come from many places. Let us see a few good sources. **Noise and Nuisance Household Sources:** Gadgets like food mixer, grinder, vacuum cleaner, washing machine and dryer, cooler, air conditioners can be very noisy and injurious to health. Others include loud speakers of sound systems and TVs, iPods and ear phones. Another example may be your neighbour’s dog barking all night everyday at every shadow it sees, disturbing everyone else in the apartment. **Noise and Nuisance Social Events:** Places of worship, discos and gigs, parties and other social events also create a lot of noise for the people living in that area. In many market areas, people sell with loud speakers; others shout out offers and try to get customers to buy their

goods. It is important to note that whey these events are not often, they can be called 'Nuisance' rather than noise pollution. **Noise and Nuisance Commercial and Industrial Activities:** Printing presses, manufacturing industries, construction sites, contribute to noise pollutions in large cities. In many industries, it is a requirement that people always wear earplugs to minimize their exposure to heavy noise. People who work with lawn mowers, tractors and noisy equipment are also required to wear noise-proof gadgets. **Noise and Nuisance Transportation**: Think of aero planes flying over houses close to busy, over ground and underground trains, vehicles on road—these are constantly making a lot of noise and people always struggle to cope with them.

2. MECHANISMS OF NOISE ATTENUATION AND SOUND ABSORPTION

The mechanism for reducing sound depends on where the sound comes from. If it is generated within a room then sound is absorbed. If it is airborne, it is originating from outside then to keep sound out it is necessary to insulate the space. And if it transmitted through the structure then the structure needs to be isolated from the source of vibration. Cellular and porous solids can be good absorbing media and they can help isolation. But they are not very good at insulation against sound. In this an incident sound wave is neither reflected nor transmitted; its energy is absorbed in the material. There are many ways by which this can happen. 1. by viscous losses as the pressure wave pumps air in and out of the cavities in the absorbers. 2. by thermal elastic damping. 3. By Helmholtz type resonators. 4. Vortex shading from sharp edges. 5. Direct mechanical damping in the material itself. There are three basic categories of sound absorbers: porous materials commonly formed of matted or spun fibres; panel (membrane) absorbers having an inflexible surface mounted over airspace; and resonators created by holes or slots connected to an enclosed volume of trapped air. The absorptive property of each type of sound absorber is influenced by the mounting method employed. **Porous absorber**: Common porous absorbers include carpets, draperies, spray-applied cellulose, aerated plaster, fibrous minerals wool and glass fibres, open-cell foam, and cast porous ceiling tiles. **Panel absorber:** Panel absorbers, are typically non-rigid, non-porous materials, which are placed over an airspace that vibrates in a flexural mode in response to sound pressure exerted by adjacent air molecules. Common panel (membrane) absorbers include thin wood panelling over framing, lightweight impervious ceilings and floors, glazing and other large surfaces capable of resonating in response to sound. Panel absorbers are usually most efficient at absorbing low frequencies. **Resonators:** Resonators typically tend to absorb sound in a narrow frequency range. Resonators include some perforated materials and materials that have openings (holes and slots). The classic example of a resonator is the Helmholtz resonator, which has the shape of a bottle. **Insulation:** Foams are not good at insulation. The degree of insulation depends on the mass law. This law means the heavier the material the better it insulates. Thus the light weight modern building, which are good for thermal insulation but not good for sound insulation. So it is better to add concrete or brick layers to the wall or floor to improve sound insulation. **Isolation:** Elastic materials and steel frames can transmit vibrations throughout the building. This type of noise is transmitted by the continuous solid part of the structure, so introducing a float in the floor can reduce it or by putting the building on resilient material and cellular materials could be useful. Putting the whole structure on resilient pads can also isolate buildings.

3. LITERATURE REVIEW

M. J. J. Nijhof et al. [1] revealed that the reduction of fan noise by one of the main noise sources in computers are the cooling fans. An important aspect of the noise they generate is tonal noise produced at the rotational frequency of the fan, the blade passing frequency (BPF), and its higher harmonics. Previous research pointed out that so-called side

resonator can be applied successfully to reduce this tonal noise. In the paper of Xiaofeng Shi et al.[2], suggested that the Side branch Helmholtz Resonators (HRs) are widely used to control low frequency tonal noise in air duct system. The passive Helmholtz resonator only works effectively over a narrow frequency range around resonance frequency. Changes in the exciting frequency and temperature will decrease the noise reduction performance. The paper of Vishal Vaidya et al.[3], emphasizes the role of resonator on transmission loss in air intake system and its sound pressure level reduction. The intake noise of an automobile induced by firing of an engine accompanies acoustic resonance of ducts of an intake system. Conventionally, the adoption of an integrated type resonator was one of possible ways to eliminate the booming noise due to acoustic resonances of air ducts. Luís M. B. C. Campos et al.[4] experimented the use of acoustic liners is a common means of noise reduction in jet engine exhausts. The quest for more effective sound absorption mechanisms in cylindrical ducts has led to the consideration of non-uniform liners, with impedance varying circumferentially, axially, or in both directions. Wojciech Lapka et al. [5] were examined a sound propagation without airflow through circular ducts with spiral element inside. Models are numerically computed in three-dimensions. The spiral element in duct is a newly analyzed acoustical element, geometrically similar to the well-known Archimedes screw. Significantly it can be applied in ducted systems, such as ventilation, air-conditioning and heat systems. This practical modification can improve a sound attenuation performance in specified band of frequency. Muhammad Hariz Khairuddin et al.[6] concluded that Resonators and mufflers have been key features in reducing duct noise especially in high SPL applications such as automotive and aerospace. Their paper provides comprehensive information on types of resonators, muffler modifications, and their comparative acoustic performance. Dizi Wu et al.[7] experimented on the Helmholtz resonator is qualified as a silencer with a narrow noise attenuation band at its designed resonance frequency. Combining several resonators in line is a possible way to produce a broader noise attenuation band. This paper focuses on improving the noise attenuation performance of a duct-resonator system at low frequency. Two types of periodic duct-resonator system are analyzed theoretically and numerically: a duct-resonator system with identical resonators and a modified duct-resonator system with periodic two-resonator arrays. Chang Chun Xu et al.[8] were experimented on car which will cause a certain degree of environmental pollution, air pollution and noise pollution. Noise inside the car includes intake noise and exhaust noise. This article will investigate how to reduce engine noise in the intake system. For the driver to create a comfortable driving environment and reduce the noise generated by the gas flow in the intake system.

4. DESIGN OF MODELS

4.1 Design of Cylindrical Duct

- Internal Diameter of a Cylindrical Duct, d = 125 mm
- External Diameter of a Cylindrical Duct, D = 128 mm
- Thickness of a Cylindrical Duct, t = 1.5 mm
- Length of a Cylindrical Duct, L = 1000 mm

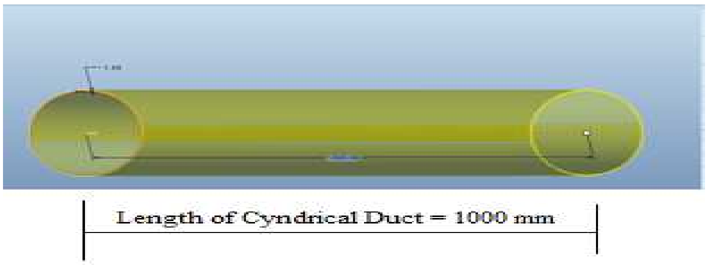

Figure 1: Cylindrical Duct.

4.2 Design of Spiral Resonator

- Lead of Spiral turn, s = 247 mm
- Diameter of mandrel, d_m = 30 mm
- Thickness of Spiral Profile, g = 3 mm
- S / d = 1.976
- d_m / d = 0.24
- g / d = 0.024

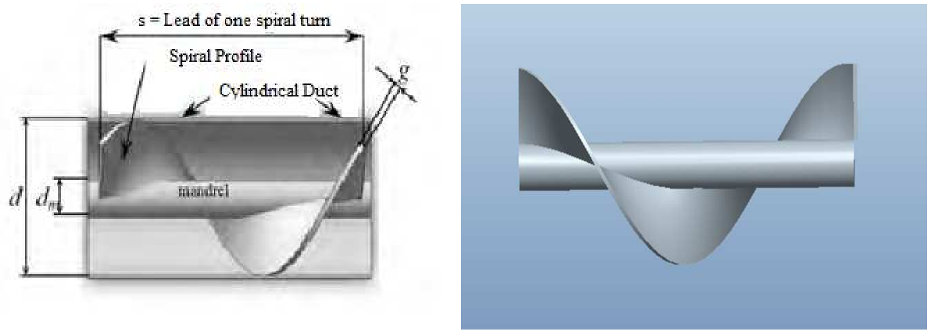

Figure 2: Basic Dimensions of Spiral Resonator.

4.3 Design of Gradual Expansion Cylindrical Duct

- Internal Diameter at Inlet, D_1 = 125 mm
- Internal Diameter at Outlet, D_2 = 300 mm
- Thickness, t = 1.5 mm

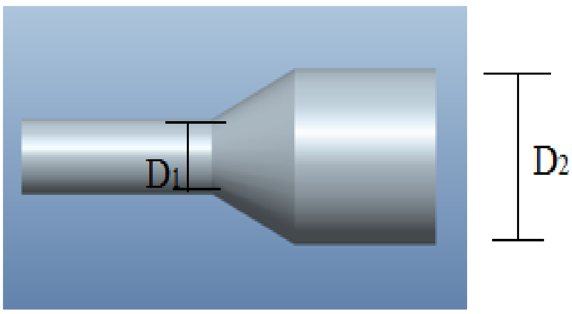

Figure 3: Design of Gradual Expansion Duct.

4.4 Design of Assembly of Spiral Resonator and Cylindrical Duct

- Distance between Inlet and first end of Spiral resonator = 460 mm.
- Material Used **:** Glass Fibre
- Composition **:** 54%SiO2-15%Al2O3-12%CaO

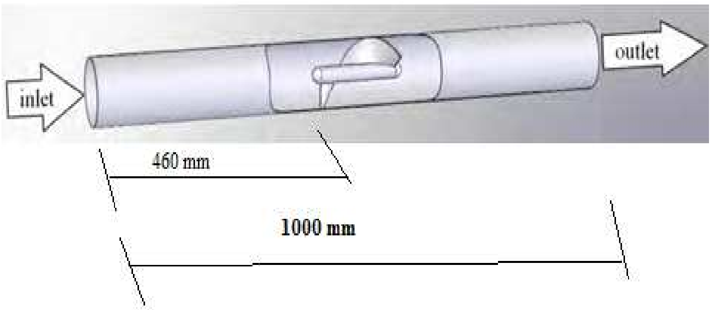

Figure 4: Schematic View of Acoustic System with Spiral Resonator to obtain Transmission Loss Computationally.

5. TEST SETUP

5.1 Design of Cylindrical Duct (Model – I)

Step-1: Open Pro ENGINEER 5.0 Wildfire, and model tree will appear at left of the workspace, here the commanded work is loaded to see the status and to select the particular in modelling.

Step-2: The sketch tool will appear to draw the model, select axis lines to make sure the reference l

Step-3: For Duct, drawn circle with 62.5mm, and extrude for 1000mm (a piece) with thick of 1.5mm.

Step-4: Final Part after Designed in Solid Mode.

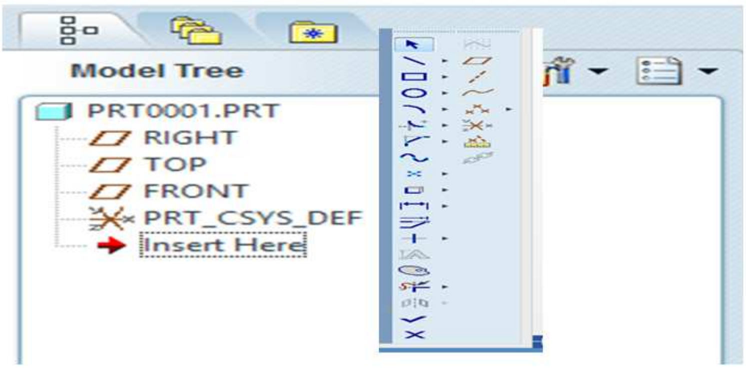

Figure 5: Model Tree & Sketcher Window Lines.

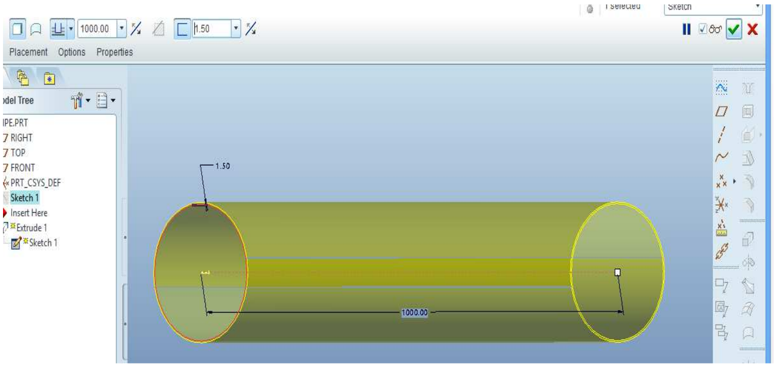

Figure 6: Part Drawing of Cylindrical Duct.

5.2 Design of Spiral Resonator in Cylidrical Duct (Model – II)

Step-1: By the helical sweep command we can produce spiral vane on surface of the solid cylinder called it as mandrel.

Figure 7: Menu Manager to Select the Type of Helical Sweep.

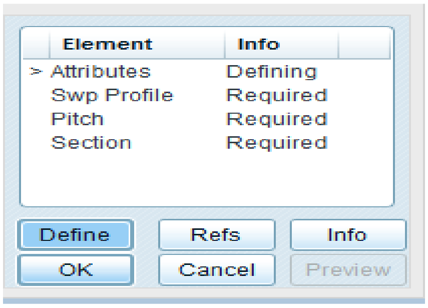

Figure 8: Settings of Shape and Size of the Helical Vane.

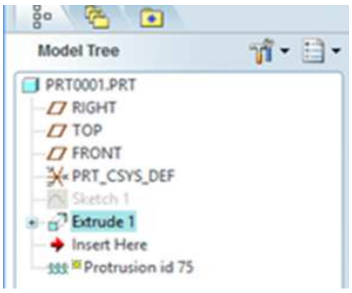

Figure 9: Model Tree for Select here to Modify the Design of Helical Sweep.

Step-2: The protrusion setup, menu manager will appear to define the spiral vane on surface of mandrel.

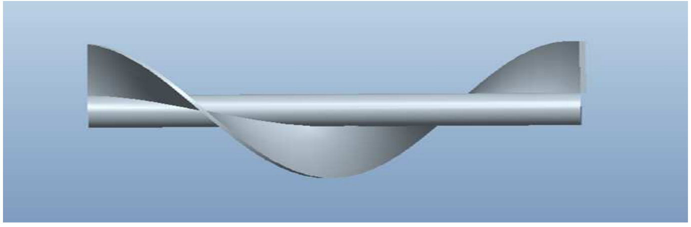

Figure 10: Resonator Part Design.

Step-3: Assembly of Cylindrical Duct and Spiral Resonator

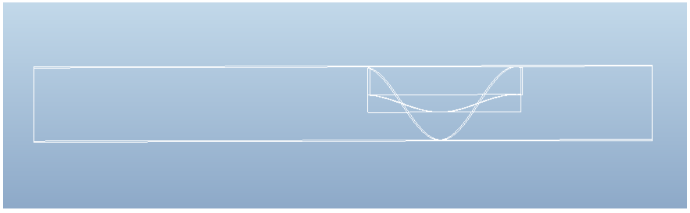

Figure 11: Cylindrical Duct with Spiral Resonator.

5.3 Design of Spiral Resonator in Gradual Expansion Cylindrical Duct (Model – III)

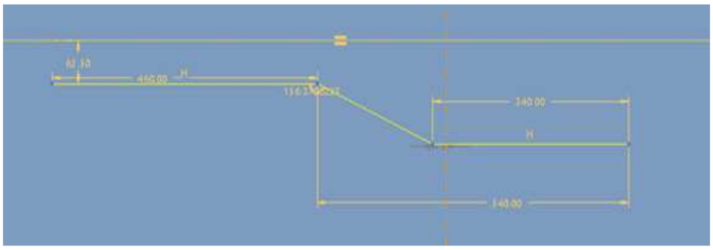

Figure 12: Line Sketch of the Gradual Expansion Duct.

The expansion duct will made by the revolve command of the sketch.

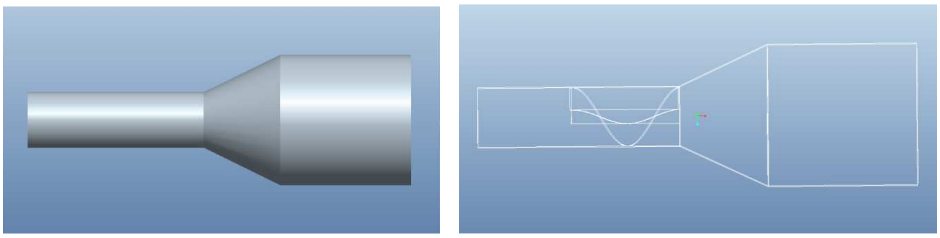

Figure 13: Spiral Resonator in Gradual Expansion Cylindrical Duct with "0"mm Offset.

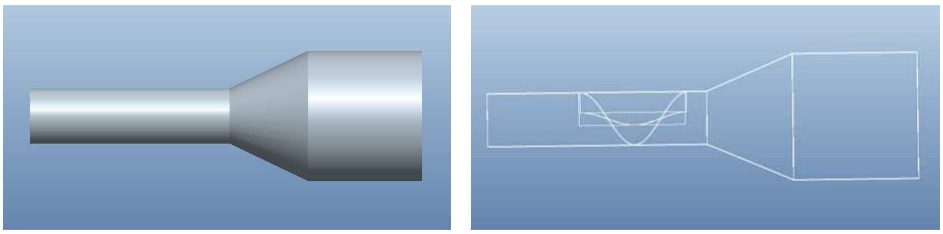

Figure 14: Spiral Resonator in Gradual Expansion Cylindrical Duct with "50" mm Offset.

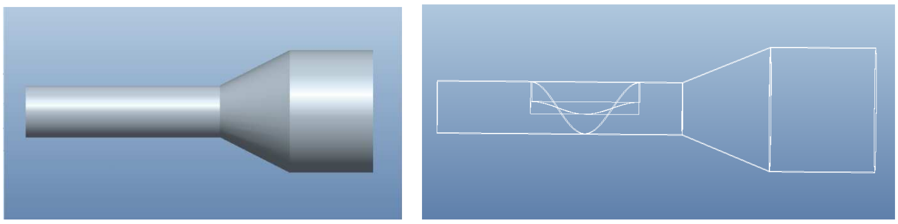

Figure 15: Spiral Resonator in Gradual Expansion Cylindrical Duct with "100" mm Offset.

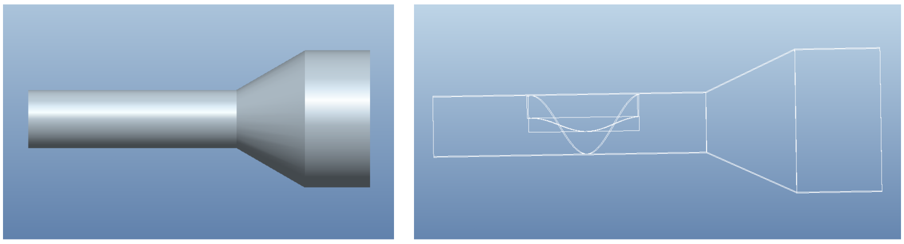

Figure 16: Spiral Resonator in Gradual Expansion Cylindrical Duct with"150" mm Offset.

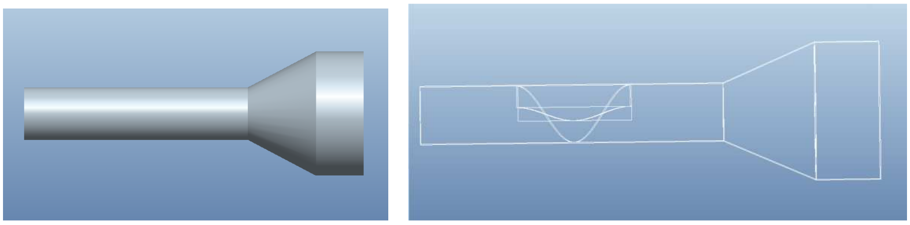

Figure 17: Spiral Resonator in Gradual Expansion Cylindrical Duct with "200" mm Offset.

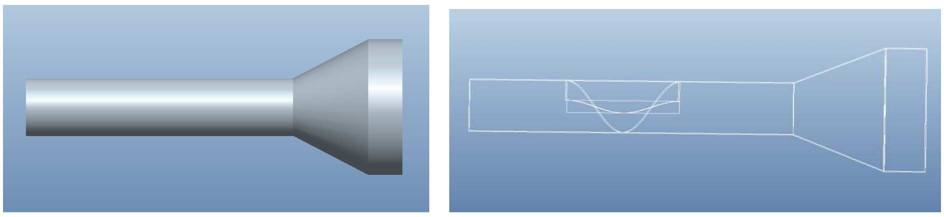

Figure 18: Spiral Resonator in Gradual Expansion Cylindrical Duct with "250" mm Offset.

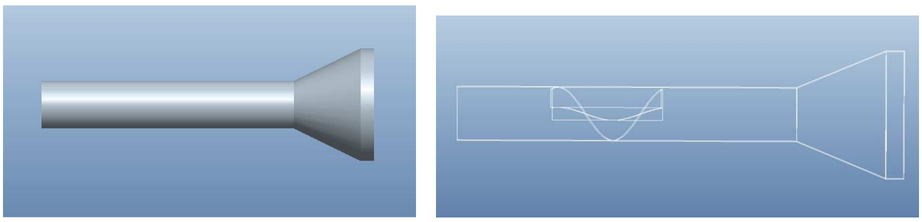

Figure 19: Spiral Resonator in Gradual Expansion Cylindrical Duct with "300" mm Offset.

5.4 Design of Double Spiral Resonator in Cylindrical Duct (Model – IV)

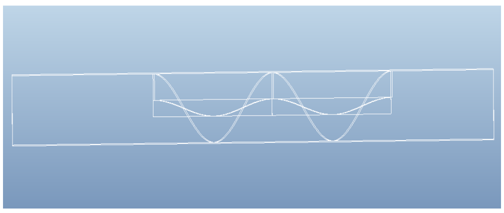

Figure 20: Double Resonator in Cylindrical Duct with "50" mm Offset.

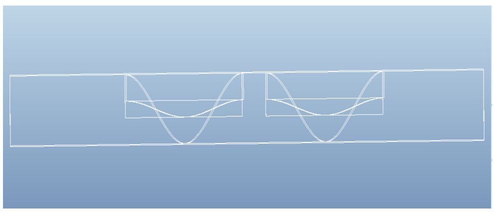

Figure 21: Double Resonator in Cylindrical Duct with "0" mm Offset.

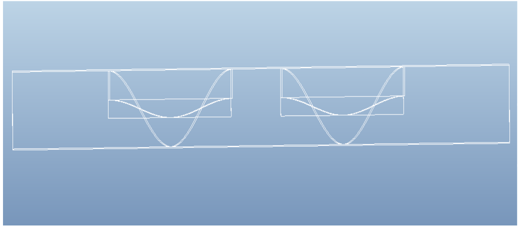

Figure 22: Double Resonator in Cylindrical Duct with "100" mm Offset.

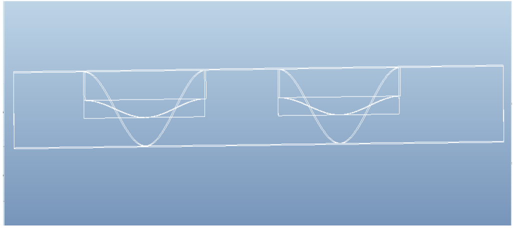

Figure 23: Double Resonator in Cylindrical Duct with "150 "mm Offset.

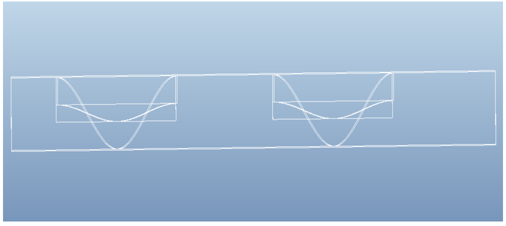

Figure 24: Double Resonator in Cylindrical with "200"mm Offset.

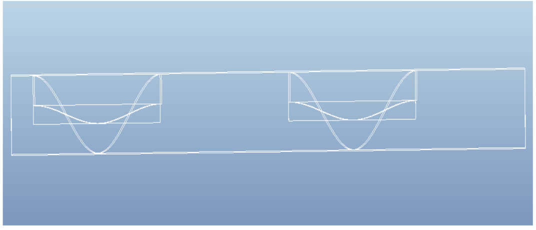

Figure 25: Double Resonator in cylindrical Duct "250" mm Offset.

6. FINITE ELEMENT ANALYSIS OF CYLINDRICAL DUCT (MODEL – I)

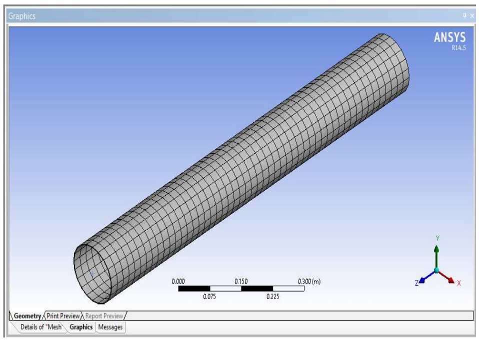

Figure 26: Meshing of Cylindrical Duct.

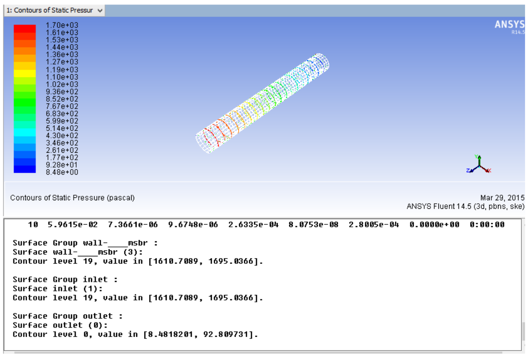

Figure 27: Inlet and Outlet Static Presssure Representation for Cylindrical Duct.

7. ANALYSIS OF SPIRAL RESONATOR IN CYLINDRICAL DUCT (MODEL – II)

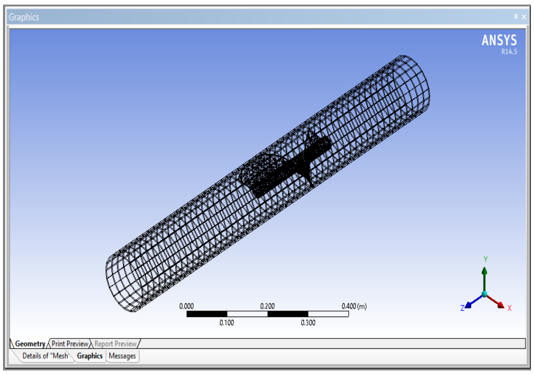

Figure 28: Meshing of Cylindrical Duct and Spiral Resonator.

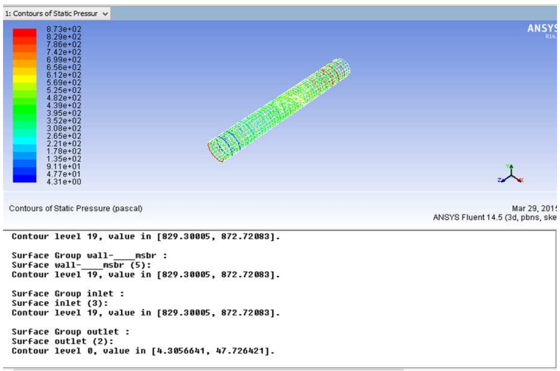

Figure 29: Inlet and Outlet Static Pressure Representation for Cylindrical Duct and Resonator Assembly.

8. ANALYSIS OF SPIRAL RESONATOR IN GRADUAL EXPANSION CYLINDRICAL DUCT (MODEL – III)

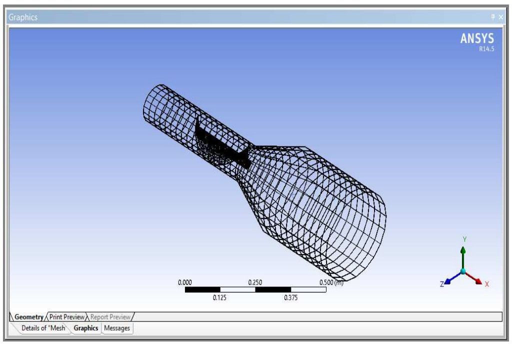

Figure 30: Meshing of Gradual Expansion Duct with Spiral Resonator Assembly at "0" mm Offset.

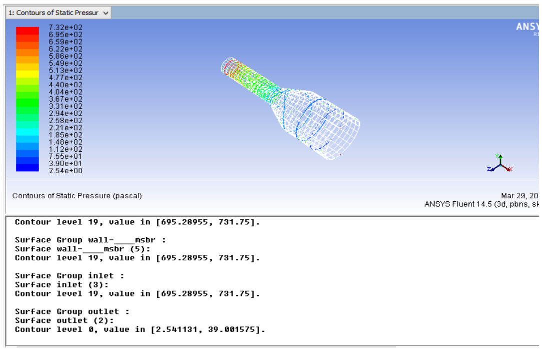

Figure 31: Inlet and Outlet Static Pressures of Gradual Expansion Duct with Spiral Resonator Assembly at "0"mm Offset.

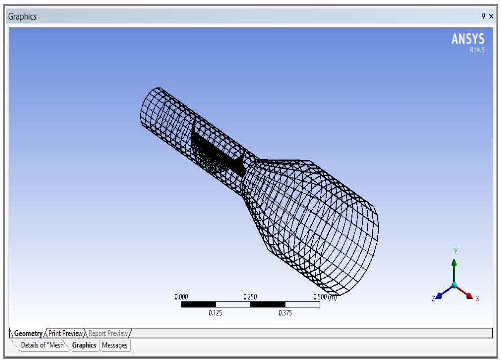

Figure 32:Meshing of Gradual Expansion Duct with Spiral Resonator Assembly at "50"mm Offset.

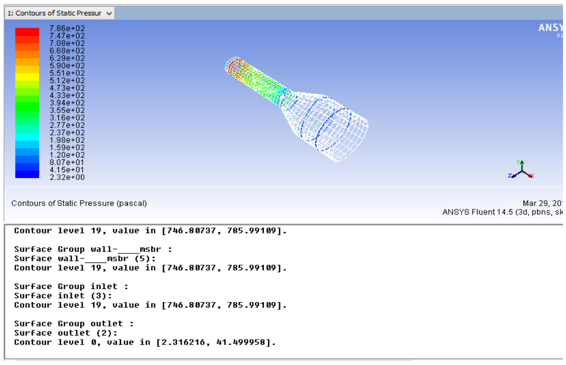

Figure 33: Inlet and outlet Static Pressures of Gradual Expansion Duct with Spiral Resonator Assembly at 50 mm Offset.

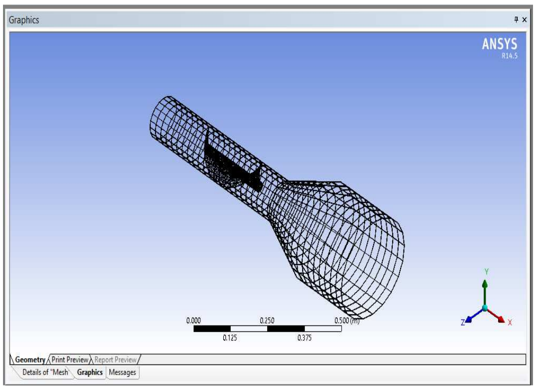

Figure 34: Meshing of Gradual Expansion Duct with Spiral Resonator Assembly at 100mm Offset.

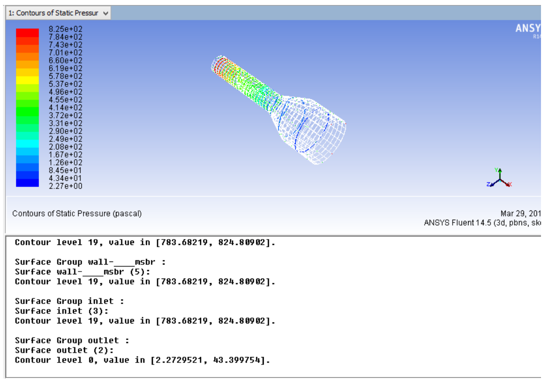

Figure 35: Inlet and Outlet Static Pressures of Gradual Expansion Duct with Spiral Resonator Assembly at "100"mm Offset.

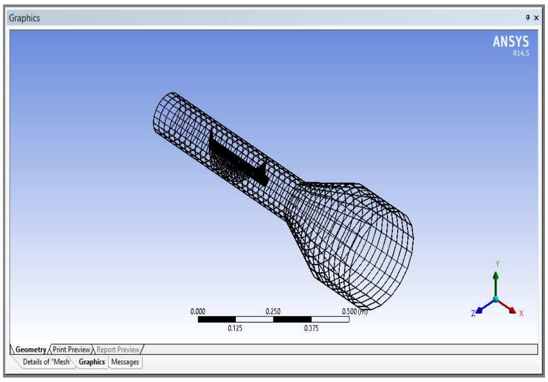

Figure 36: Meshing of Gradual Expansion Duct with Spiral Resonator Assembly at "150" mm Offset.

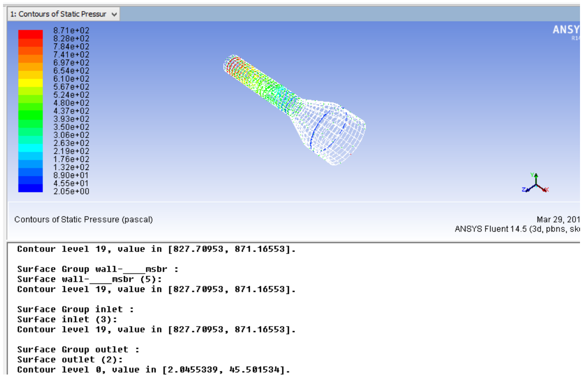

Figure 37: Inlet and Outlet Static Pressures of Gradual Expansion Duct with Spiral Resonator Assembly at "150"mm Offset.

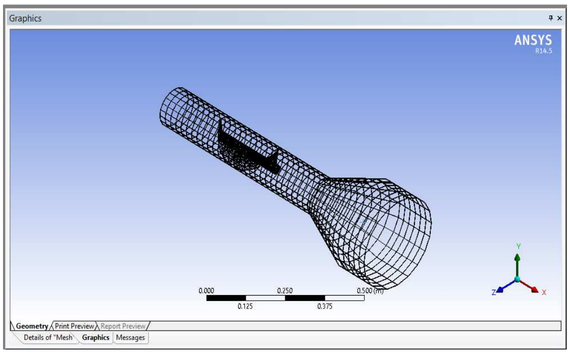

Figure 38: Meshing of Gradual Expansion Duct with Spiral Resonator Assembly at "200" mm Offset.

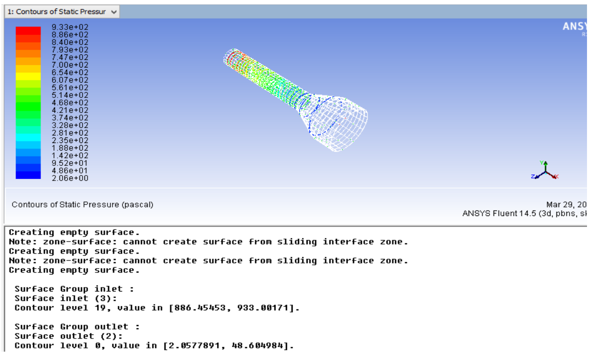

Figure 39:Inlet and Outlet Static Pressures of Gradual Expansion Duct with Spiral Resonator Assembly at "200"mm Offset.

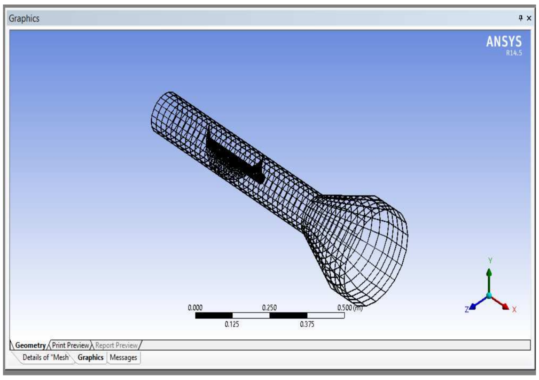

Figure 40: Meshing of Gradual Expansion Duct with Spiral Resonator Assembly at "250"mm.

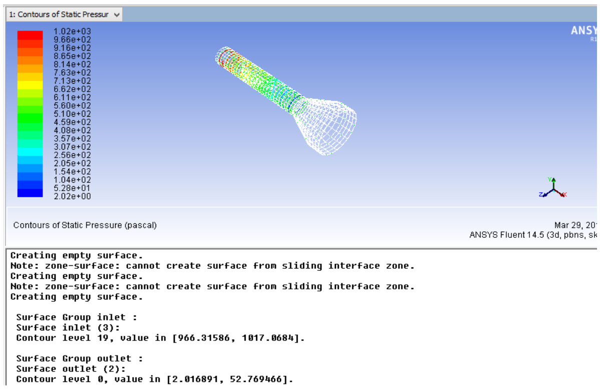

Figure 41: Inlet and Outlet Static Pressures of Gradual Spiral Resonator Assembly at "250"mm offset Expansion Duct with Offset.

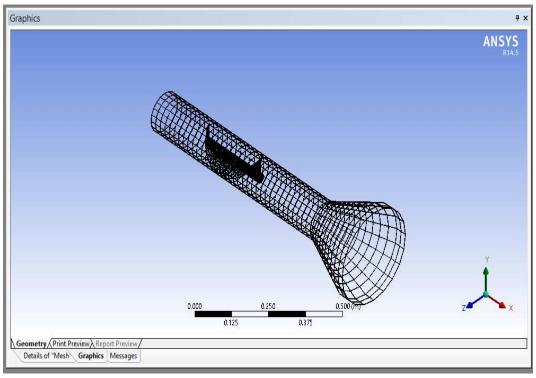

Figure 42: Meshing of Gradual Expansion Duct with Spiral Resonator Assembly at "300"mm Offset.

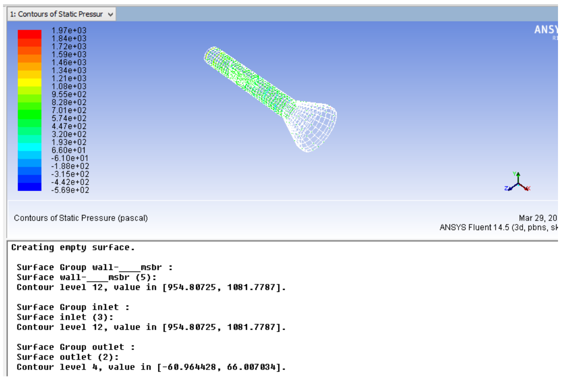

Figure 43: Inlet and Outlet Static Pressures of Gradual Expansion Duct with Spiral Resonator Assembly at "300"mm Offset.

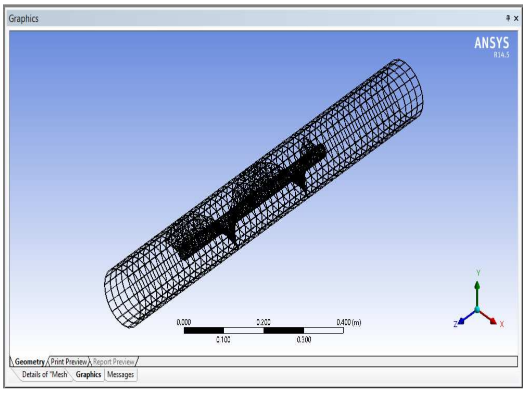

Figure 44: Meshing of Dual Spiral Resonators in Cylindrical Duct at " 0"mm Offset.

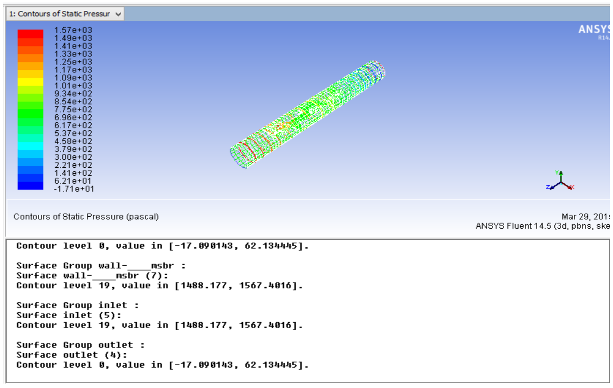

Figure 45: Inlet and Outlet Static Pressures of Dual Spiral Resonators in Cylindrical Duct Assembly at "0"mm Offset.

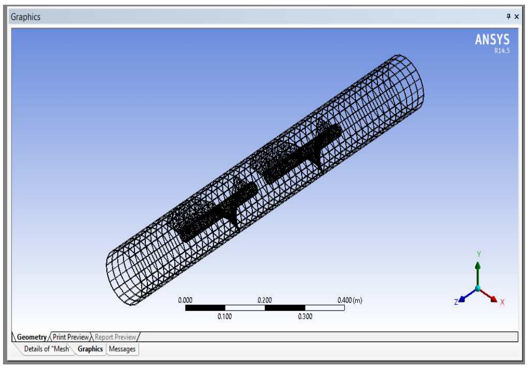

Figure 46: Meshing of Dual Resonators in Cylindrical Duct at "50" mm Offset.

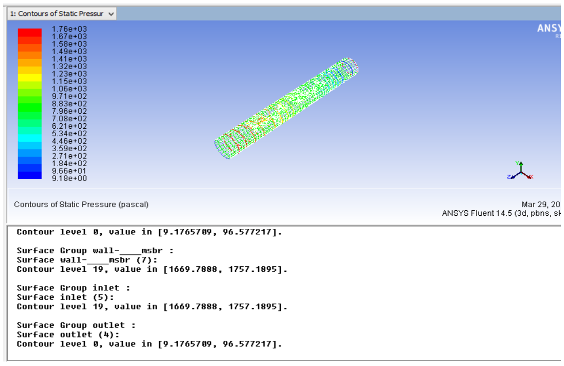

Figure 47: Inlet and Outlet Static Pressures of Dual Spiral Resonators in Cylindrical Duct Assembly at" 50" mm Offset.

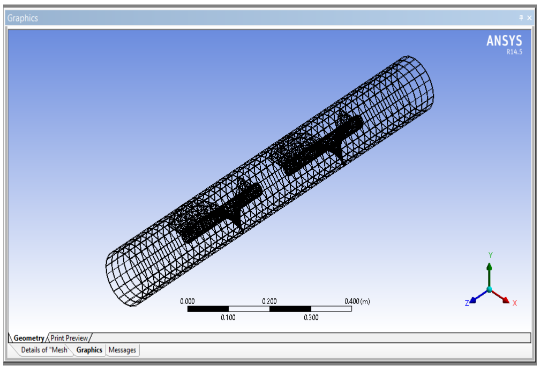

Figure 48: Meshing of Dual Resonators in Cylindrical Duct at "100" mm Offset.

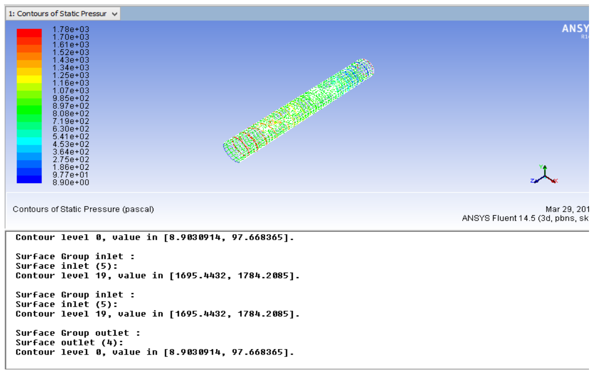

Figure 49: Inlet and Outlet Static Pressures of Dual Spiral resonators in Cylindrical Duct Assembly at "100" mm Offset.

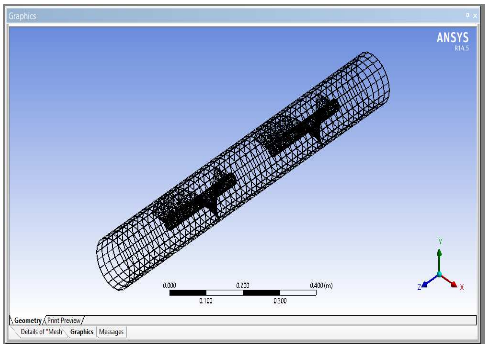

Figure 50: Meshing of Dual Resonators in Cylindrical Duct at " 150" mm Offset.

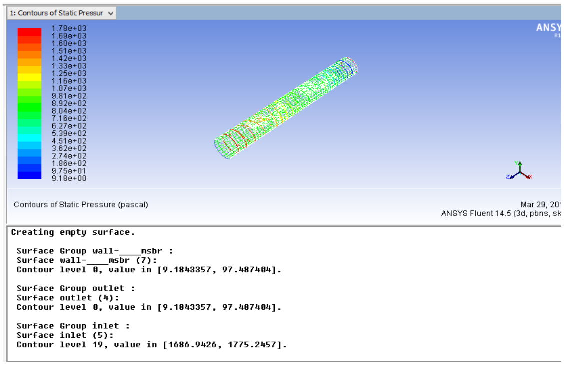

Figure 51: Inlet and Outlet Static Pressures of Dual Spiral Resonators in Cylindrical Duct Assembly at "150" mm Offset.

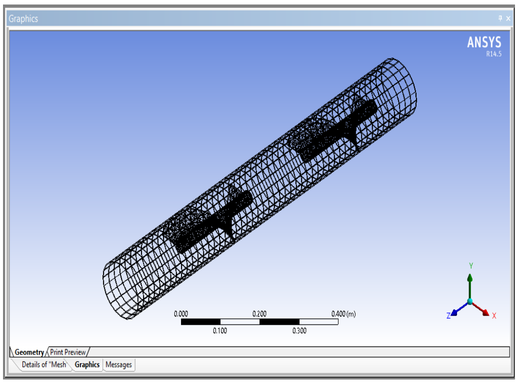

Figure 52: Meshing of Dual Resonators in Cylindrical Duct at "200" mm.

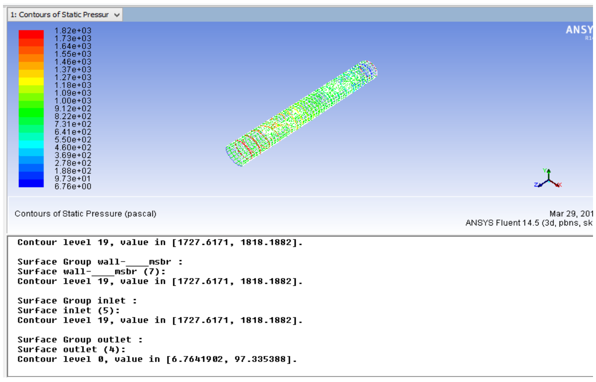

Figure 53: Inlet and Outlet Static Pressures of Dual Spiral Offset Resonators in Cylindrical Duct Assembly at "200" mm Offset.

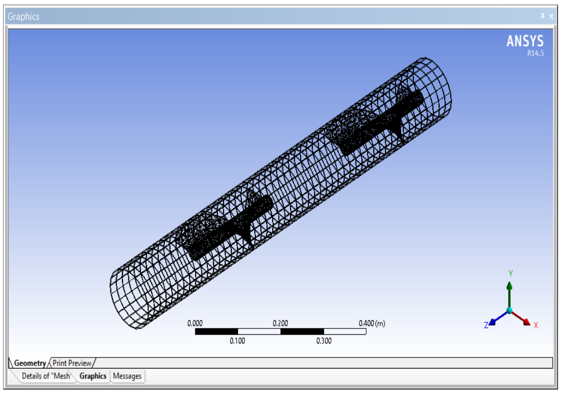

Figure 54: Meshing of Dual Spiral Resonators in Cylindrical Duct Assembly at" 250"mm Offset.

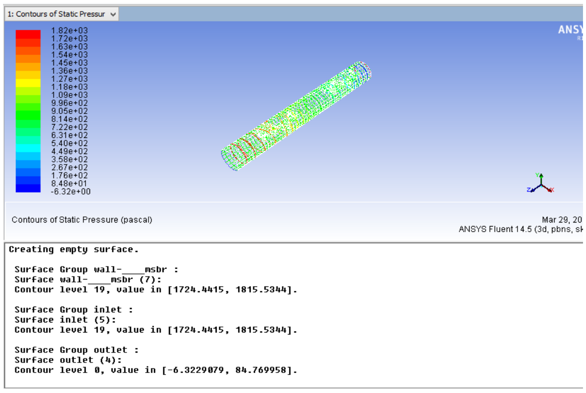

Figure 55: Inlet and Outlet Static Pressures of Dual Spiral Resonators in Cylindrical Duct Assembly at "250"mm Offset.

9. RESULTS OF THE CYLINDRICAL DUCT ANALYSIS

By using the ANSYS tool, Static pressures for cylindrical duct given as below.

Table 1

S. No.	Static Pressure at Inlet	Static Pressure at Outlet
1	1610.7089	92.809563

9.1 Transmission Loss

The Transmission Loss (TL) is expressed as the difference between the outgoing power at the outlet w_o and the incoming power at the inlet w_i

Transmission Loss = 10 $\log_{10}(w_i/w_0)$ dB

Where $w_i = p_0^2/2\rho_0 Cs$

$w_0 = p_2^2/2\rho_0 Cs$

p_0 - maximum amplitude of source sound pressure at the inlet (Pa)

p_2 - maximum amplitude of source sound pressure at the outlet (Pa)

ρ_0 - the density of air (1.23 kg/m^3)

Cs -the speed of sound in air (343 m/s)

Then,

Incoming power, Wi = $(1610.7089)^2/(2\times1.23\times343)$

= 3074.715163 dB

Outgoing power, Wo = $(92.809563)^2/(2\times1.23\times343)$

= 2.69953218 dB

Therefore, transmission loss (TL) = 10 $\log_{10}$ (3074.715163 / 2.69953218)

= 24.7884866 dB

Below Table Shows Calculated data for Cylindrical Duct

Table 2

S. No.	Static Pressure at Inlet	Static Pressure at Outlet	Incoming Power (Wi)	Outgoing Power (Wo)	Transmission Loss (TL)
1	1610.7089	92.809563	3 74.715163	10.20836591	24.78848661

9.2 Spiral Resonator in Cylindrical Duct

By using the ANSYS tool, Static pressures for assembly of spiral resonator in cylindrical duct as shown below

Table 3

S. No.	Static Pressure at Inlet	Static Pressure at Outlet
1	829.30005	47.726421

Then,

Incoming power, Wi = $(1610.7089)^2 / (2\times1.23\times343)$

= 815.068588 dB

Outgoing power, Wo = $(92.809563)^2 / (2\times1.23\times343)$

= 2.69953218 dB

Therefore, transmission loss (TL) = $10 \log_{10} (3074.715163 / 2.69953218)$

= 24.7990565 dB

Below Table Shows Calculated data for assembly of spiral resonator in cylindrical duct

Table 4

S. No.	Static Pressure at Inlet	Static Pressure at Outlet	Incoming Power (Wi)	Outgoing Power (Wo)	Transmission Loss (TL)
1	829.30005	47.726421	815.068588	2.69953218	24.7990565

9.3 Spiral Resonator in Gradual Expansion Cylindrical Duct

By using the ANSYS tool, Static pressures for assembly of spiral resonator in gradual expansion cylindrical duct as shown below

Table 5

S. No.	Static Pressure at Inlet	Static Pressure at Outlet
1	823.40002	46.4443393
2	856.83868	47.865444
3	935.82153	52.192799
4	988.44855	54.712601
5	1041.0404	57.494301
6	1097.2675	60.307487

Then, Incoming power, Wi = $(823.40002)^2 /(2\times1.23\times343)$ = 2624.696389 dB

Outgoing power, Wo = $(46.4443393)^2 / (2\times1.23\times343)$ = 4.57546343 dB

Therefore,

Transmission loss (TL) = 10 $\log_{10}$ (3074.715163 / 2.69953218) = 27.58643985 dB

And, the remaining values of Incoming Power, Outgoing Power and Transmission loss are obtained as shown in below Table.

Table 6

S. No.	S Static Pressure at Inlet	S Static Pressure at outlet	Incoming Power(Wi)	Outgoing Power(Wo)	Transmission Loss(TL)
1	823.40002	46.4443393	803.5122816	2.556444397	24.97356168
2	856.83868	47.865444	870.0994614	2.715282099	25.05753943
3	935.82153	52.192799	1037.903169	3.228434269	25.07164889
4	988.44855	54.712601	1157.920946	3.547688625	25.13733415
5	1041.0404	57.494301	1284.41669	3.917602512	25.15685571
6	1097.2675	60.307487	1426.907448	4.310356951	25.19882568

9.4 Dual Spiral Resonator in Cylindrical Duct

By using the ANSYS tool, Static pressures for assembly of dual spiral resonator in cylindrical duct below Table Shows

Table 7

S. No.	Static Pressure at Inlet	Static Pressure at Outlet
1	1488.1755	62.134407
2	1669.7888	92.577217
3	1695.4446	97.668434
4	1686.9426	97.487404
5	1727.6171	97.335388
6	1724.4415	84.769958

Then, Incoming power, Wi = $(1488.1755)^2/(2\times1.23\times343)$ = 2624.696389 dB

Outgoing power, Wo = $(62.134407)^2/(2\times1.23\times343)$ = 4.57546343 dB

Therefore,

Transmission loss (TL) = 10 $\log_{10}$ (3074.715163 / 2.69953218) = 27.58643985 dB

And, the remaining values of incoming power, outgoing power and transmission loss and are obtained as, shown in below table

Table 8

S. No.	S Static Pressure at Inlet	Static Pressure at Outlet	Incoming Power(Wi)	Outgoing Power(Wo)	Transmission Loss(TL)
1	1488.1755	62.134407	2 624.696389	4.57546343	27.58643985
2	1669.7888	92.577217	3 304.409487	10.1573172	25.12314845
3	1695.4446	97.668434	3 406.732077	11.3052253	24.79058758
4	1686.9426	97.487404	3 372.650852	11.2633553	24.763036
5	1727.6171	97.335388	3 537.250046	1 1.22825589	24.98353459
6	1724.4415	84.769958	3 524.258085	8.516373675	26.16812996

10. CONCLUSIONS

10.1 Comparison of Transmission Losses in Cylindrical Duct (Model – I) and Spiral Resonator in Cylindrical Duct (Model – II)

- Transmission Loss in Cylindrical Duct is 24.78848661 dB

- Transmission Loss in Spiral resonator in Cylindrical duct is 24.7990565 dB
- By comparison of Transmission Losses in above two models, it was more in Spiral resonator in Cylindrical Duct.

10.2 Comparison of Transmission Losses in Cylindrical Duct (Model – I) and Spiral Resonator in Gradual Expansion Cylindrical Duct (Model – III)

- Transmission Loss in Cylindrical Duct for all offsets is 24.78848661 dB
- Transmission Loss in Spiral resonator in Gradual Expansion Cylindrical Duct for different offsets is given below. Below Table Shows Transmission loss for Gradual Expansion in cylindrical duct for following offsets

Table 9

S. No.	Off Set (mm)	Transmission Loss(TL in dB)
1	0	24.97356168
2	50	25.05753943
3	100	25.07164889
4	150	25.13733415
5	200	25.15685571
6	250	25.19882568

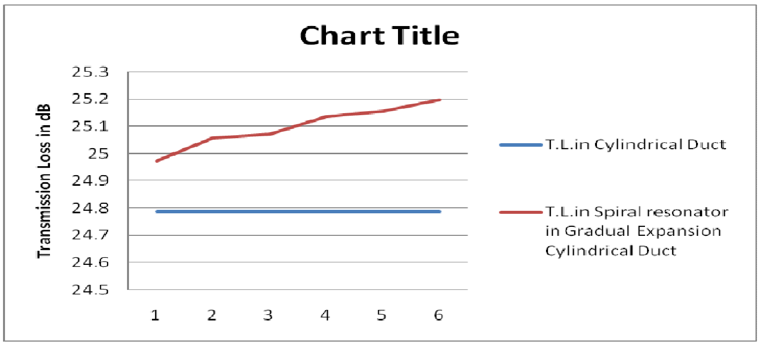

Figure 56: Graphical Comparison of Transmission Loss.

By comparison of Transmission Losses in above two models it was concluded that it as more in Spiral Resonator in Gradual Expansion Cylindrical Duct.

10.3 Comparison of Transmission Losses in Cylindrical Duct (Model – I) and Double Spiral Resonator in Cylindrical Duct (Model – IV)

- Transmission Loss in Cylindrical Duct for all offsets is 24.78848661 dB
- Transmission Loss in Spiral resonator in Double Spiral Resonator in Cylindrical Duct for different offsets is given below. Below Table Shows Transmission loss for Gradual Expansion in cylindrical duct for following offsets

Table 10

S. No.	Off Set (mm)	Transmission Loss(TL)
1	0	27.58643985
2	50	25.12314845
3	100	24.79058758
4	150	24.763036
5	200	24.98353459
6	250	26.16812996

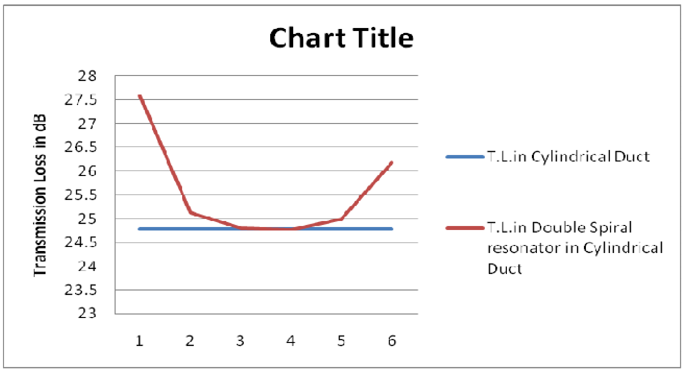

Figure 57: Graphical Comparison of Transmission Loss.

By comparison of Transmission Losses in above two models we conclude it as in we can get more in Double Spiral resonator in Cylindrical Duct. By observing the above values and figures by using the Spiral Resonator in Cylindrical Duct with varying cross section will get more Transmission Loss than simple Cylindrical Duct. The acoustic attenuation performance of Spiral Resonator due to distance change from two different cross-sectional elements of cylindrical duct was considered: Model – III case - expansion chamber, Model- IV case - Double Spiral Resonator. The acoustic attenuation performance of Model- III is increases with increase the distance between Spiral Resonator and the inlet of the Gradual Expansion Chamber. In Model - IV, there is visible strong minimization of sound attenuation of two Spiral resonators when placing them one by one. Presented results show that Spiral Resonator can be an effective additional sound attenuation element for ducted systems. This research work doesn't present all spectrum of possible use of this solution, also further research.

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